20th ONERA-DLR Aerospace Symposium
17. – 19. November 2020

Climate impact of contrail cirrus

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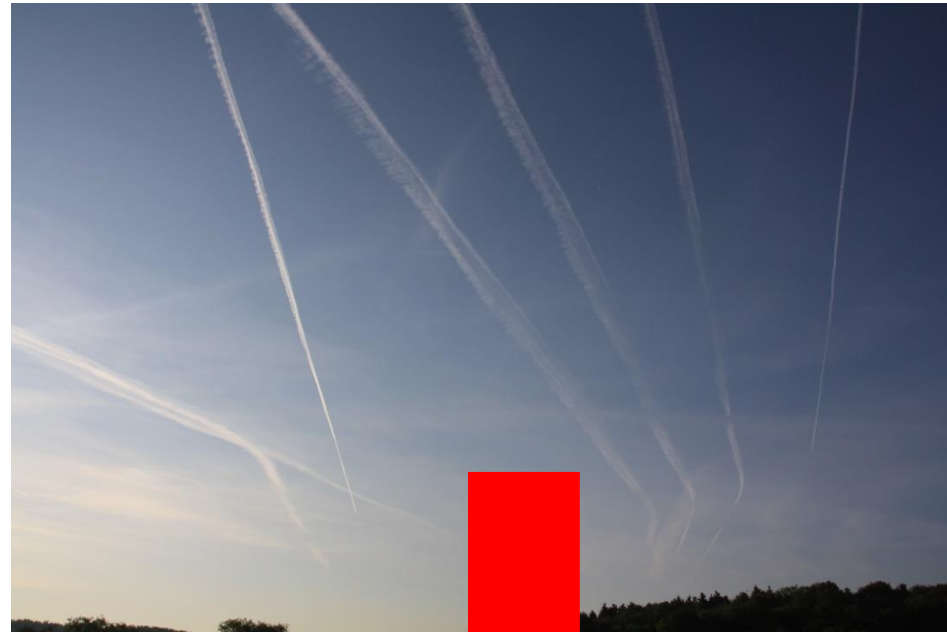
What is contrail cirrus?

Linear contrails



Contrail cirrus

- Lose their line-shaped form
- Persist over many hours
- Spread over large areas
- Optical thin (τ mostly below 0.5)
- Hardly distinguishable from natural cirrus clouds

Global climate impact of contrail cirrus

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Measurements

not available

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Simulations

Temperature change simulations:
Direct determination of **ΔT_{surf}**

↓

- Computational expensive
- Coupled ocean needed

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Determination of net radiative balance at top of atmosphere:
RF

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+ → warming
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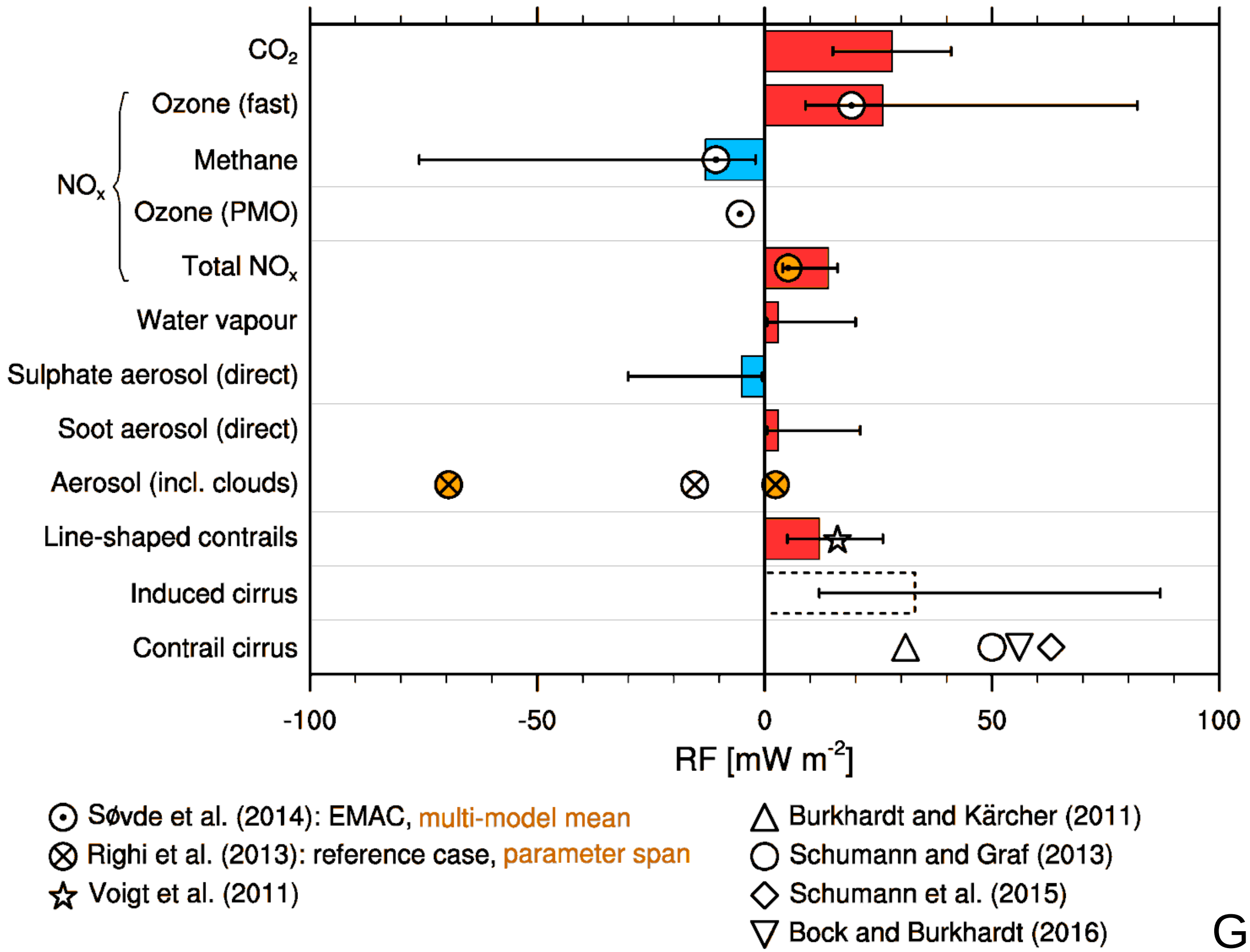
$$\Delta T_{surf} = \lambda \cdot RF$$

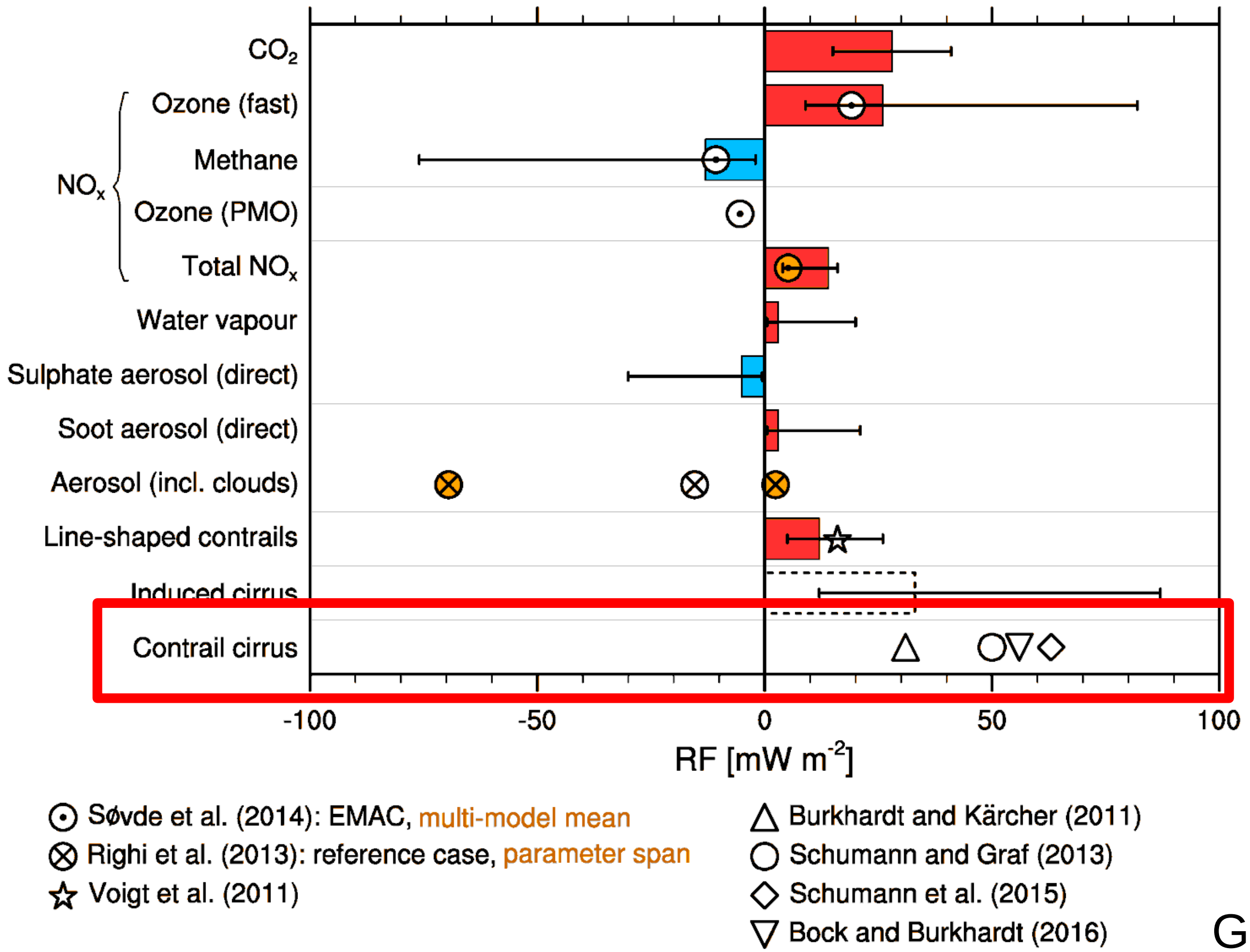
λ: climate sensitivity [$Wm^{-2}K^{-1}$]

Global climate impact of contrail cirrus



Grewe et al., 2017

Global climate impact of contrail cirrus



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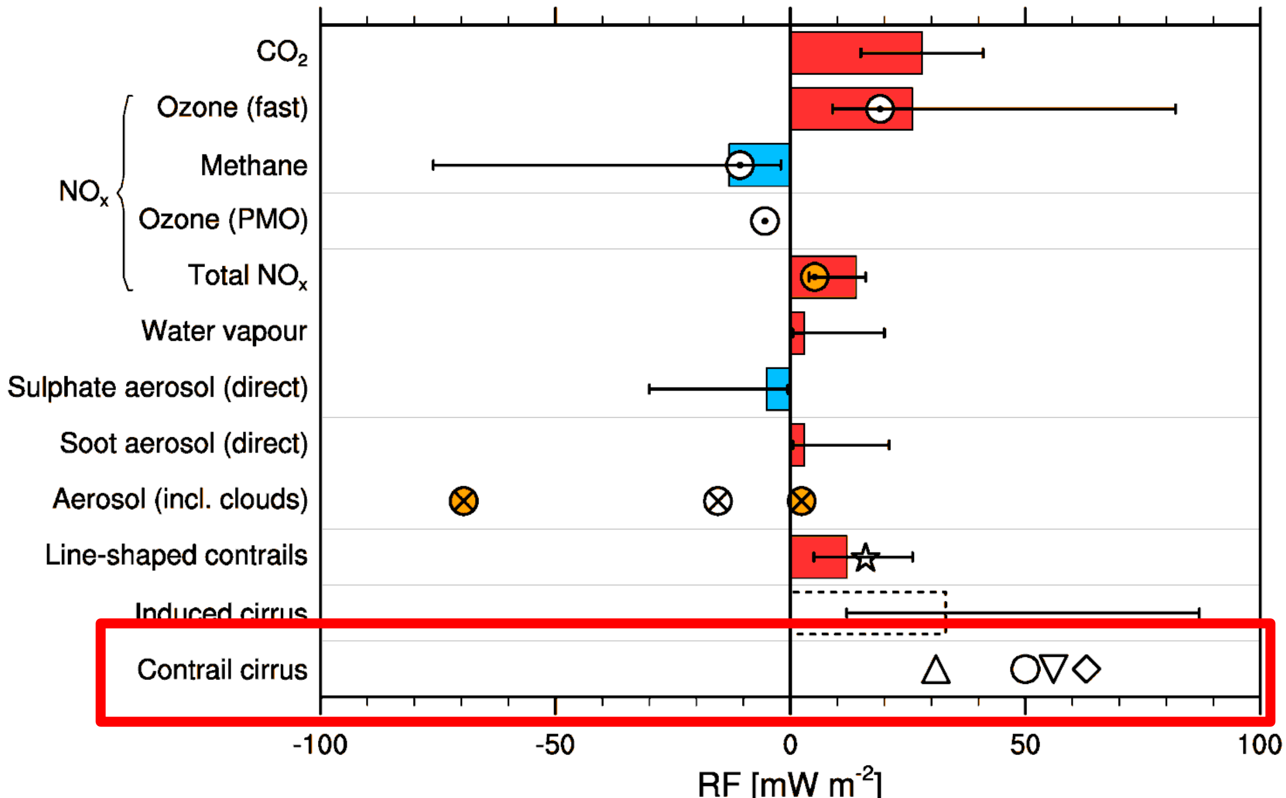

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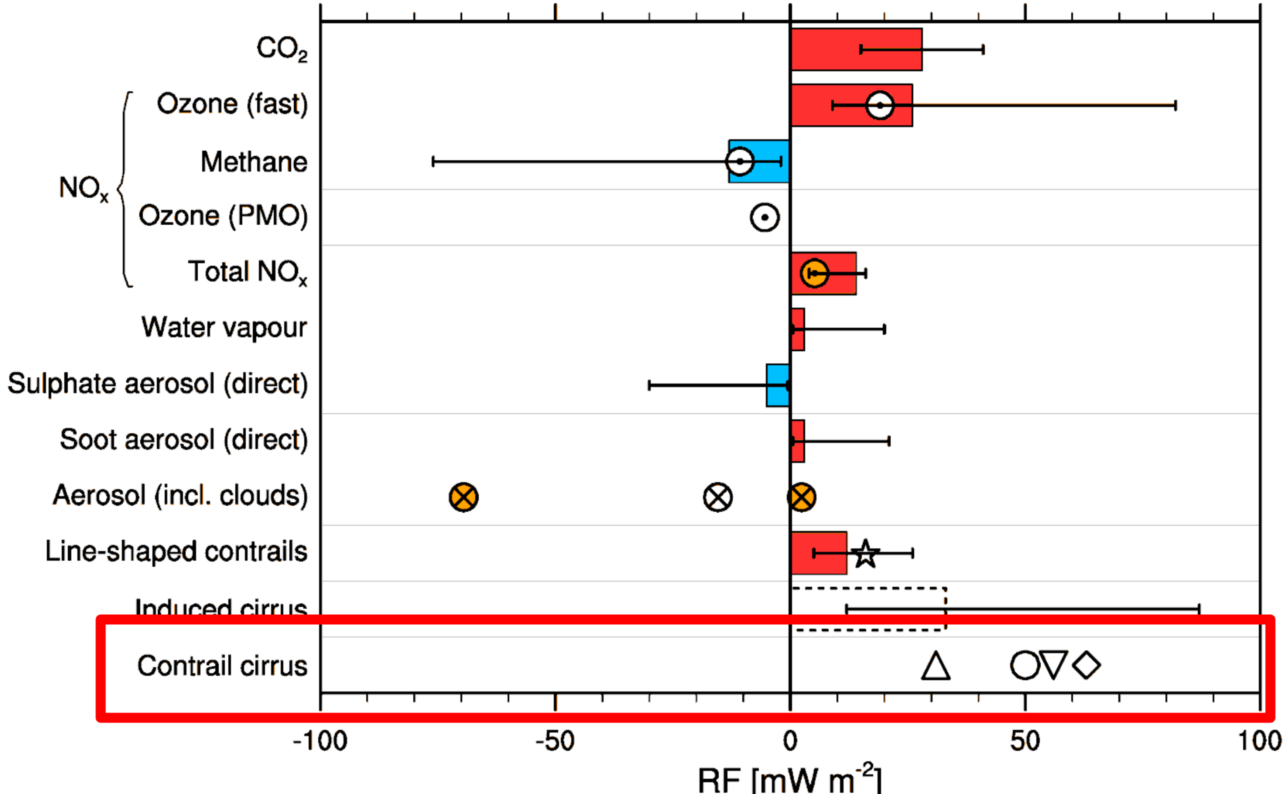

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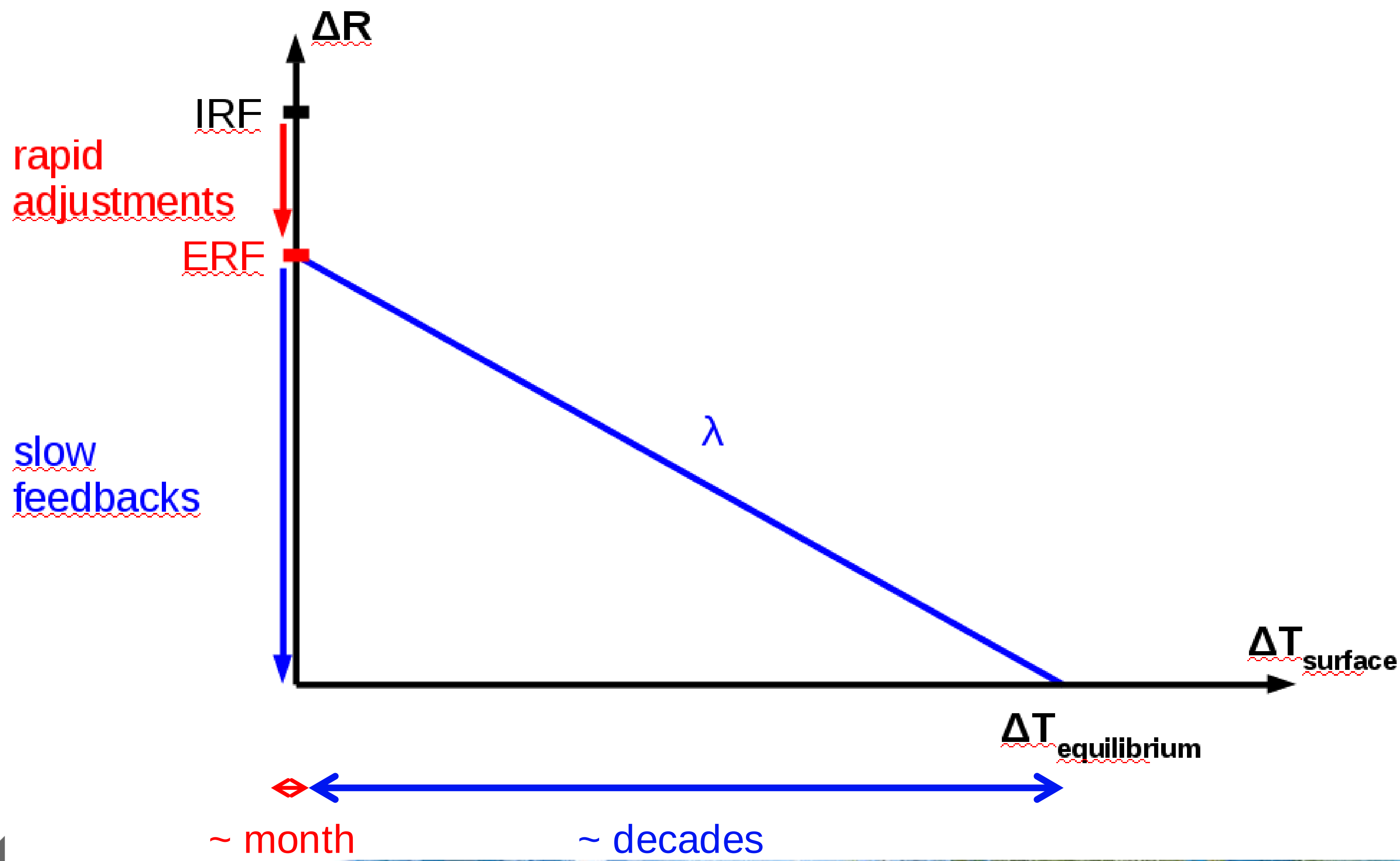
λ: climate sensitivity [$Wm^{-2}K^{-1}$]

Grewe et al., 2017

but: λ may be dependent on forcing

Radiative Forcings, Rapid Adjustments and Slow Feedbacks



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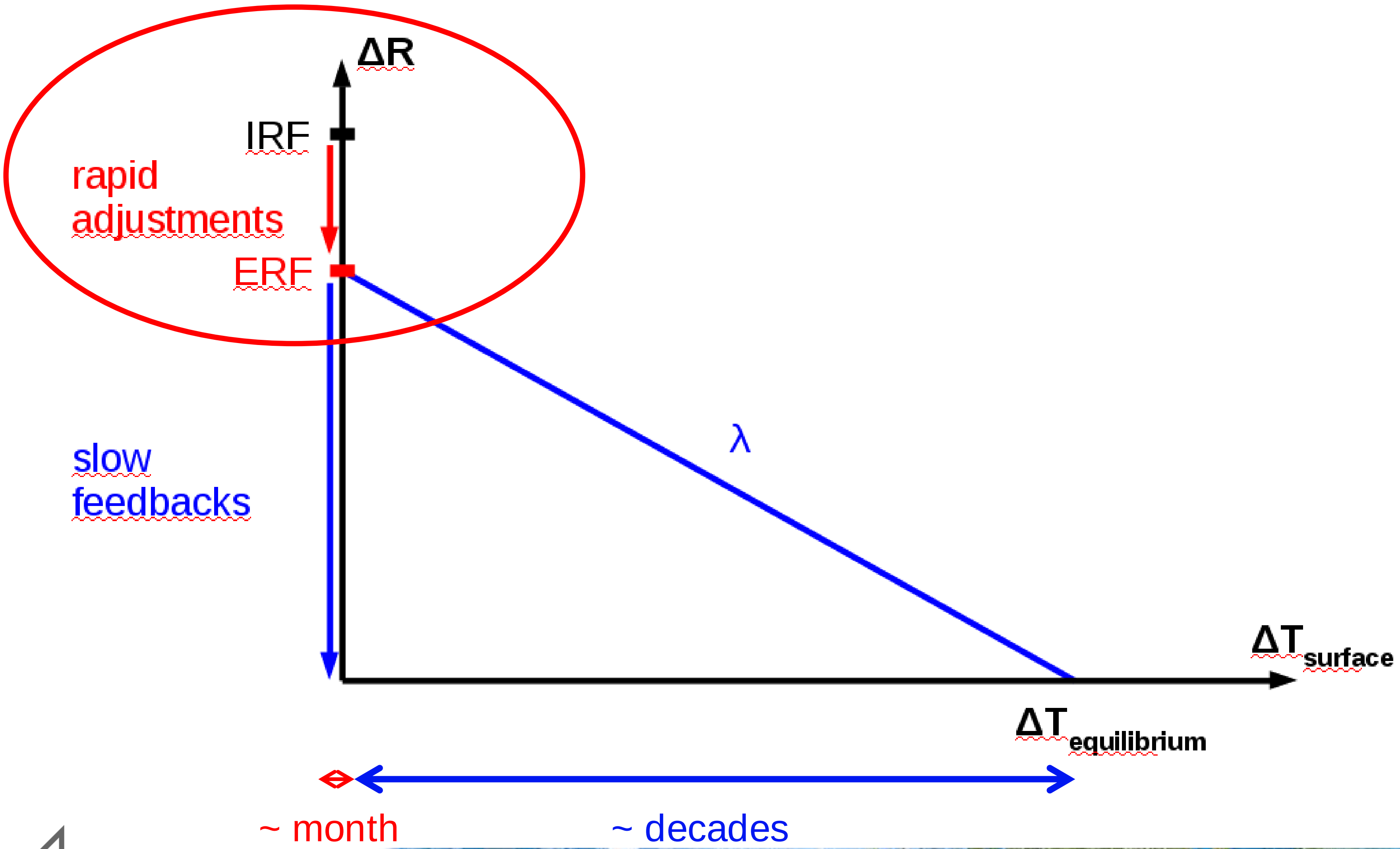

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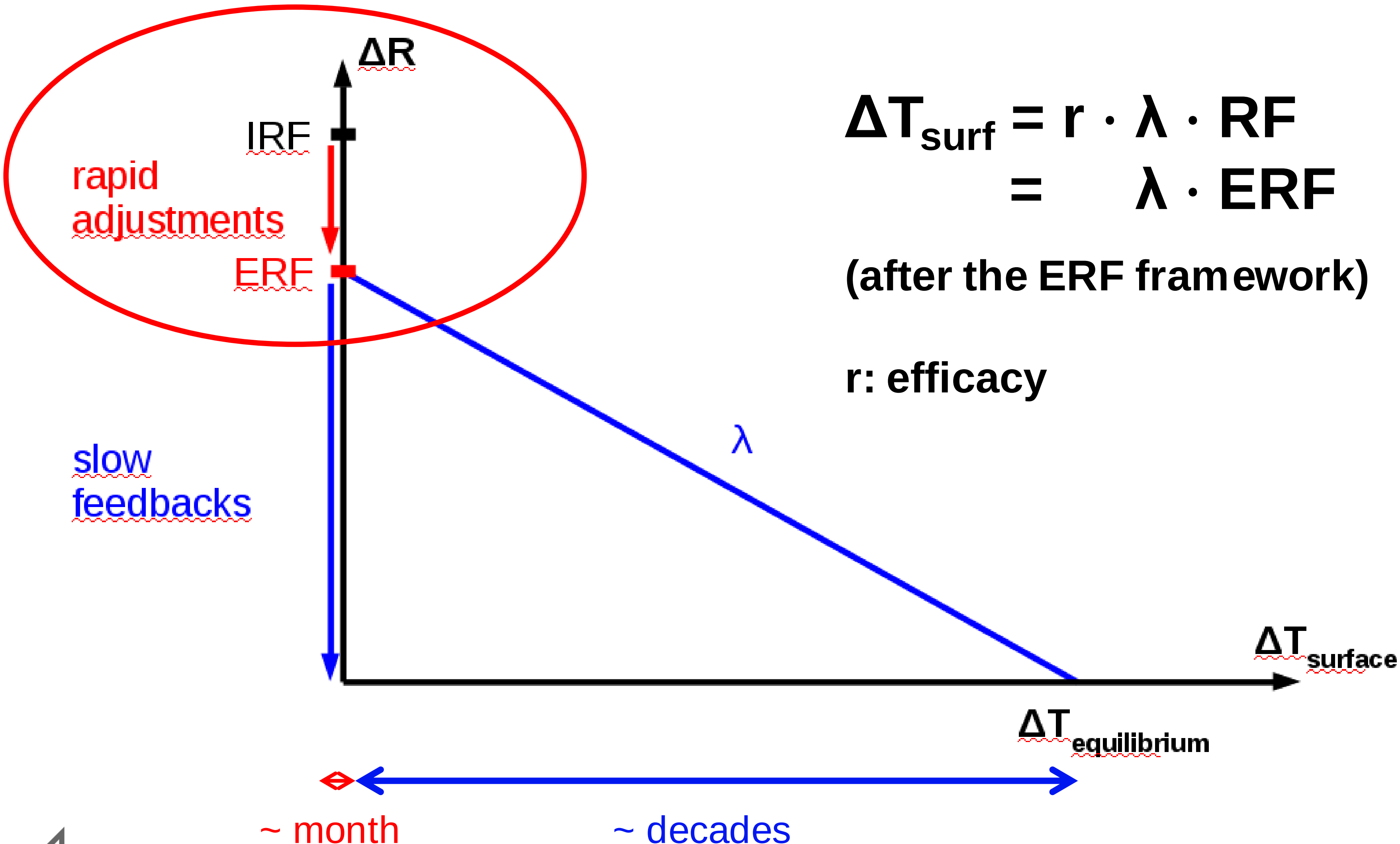


$$\Delta T_{surf} = r \cdot \lambda \cdot RF$$
$$= \lambda \cdot ERF$$

(after the ERF framework)

r: efficacy

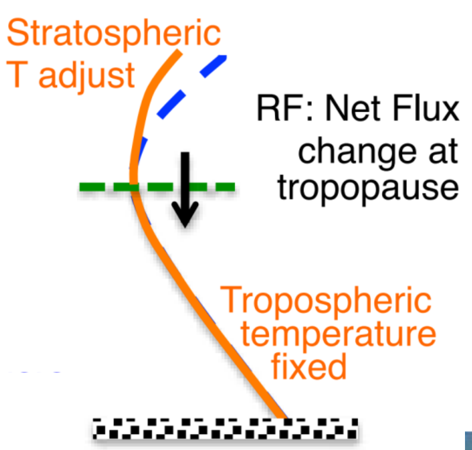
Modell Setup

- ECHAM5 climate model, resolution: 2.8° (horizontal), 600m (vertical)
- Contrail cirrus parametrization: Bock und Burkhardt (2016)

  ↳ two-moment scheme (Ice water content und Ice crystal number concentration)
- AEDT 2050 air traffic data set (Water vapor emissions and Air traffic density)

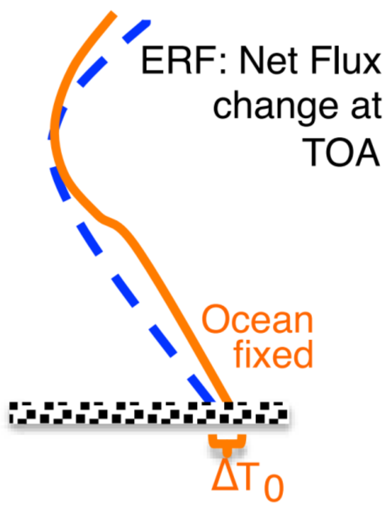
Conventional RF simulations:

- Calculation of RF within one simulation (radiation double calling)
- ~5 years / simulation



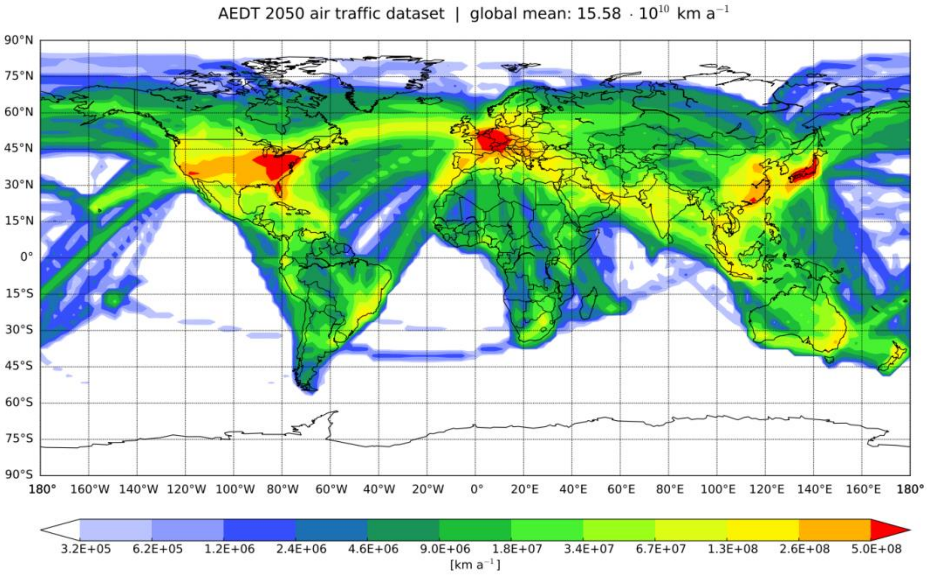
ERF simulations:

- FSST method
- 2 independent simulations: Reference und Experiment
- ~30 years / simulation



IPCC, 2008

Air traffic and Radiative Forcing



Air traffic (Wilkerson et al., 2011):

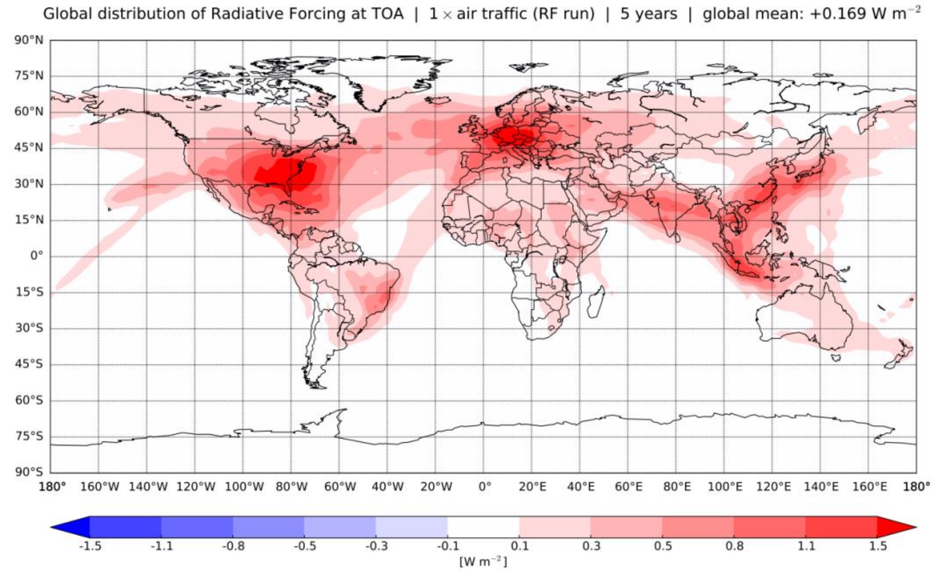
2006: $38.2 \cdot 10^9$ km / year (AEDT 2006)

2050: $155.8 \cdot 10^9$ km / year (AEDT 2050)

Radiative Forcing:

2006: 56 mW m^{-2} (Bock and Burkhardt, 2016)

2050: 169 mW m^{-2}



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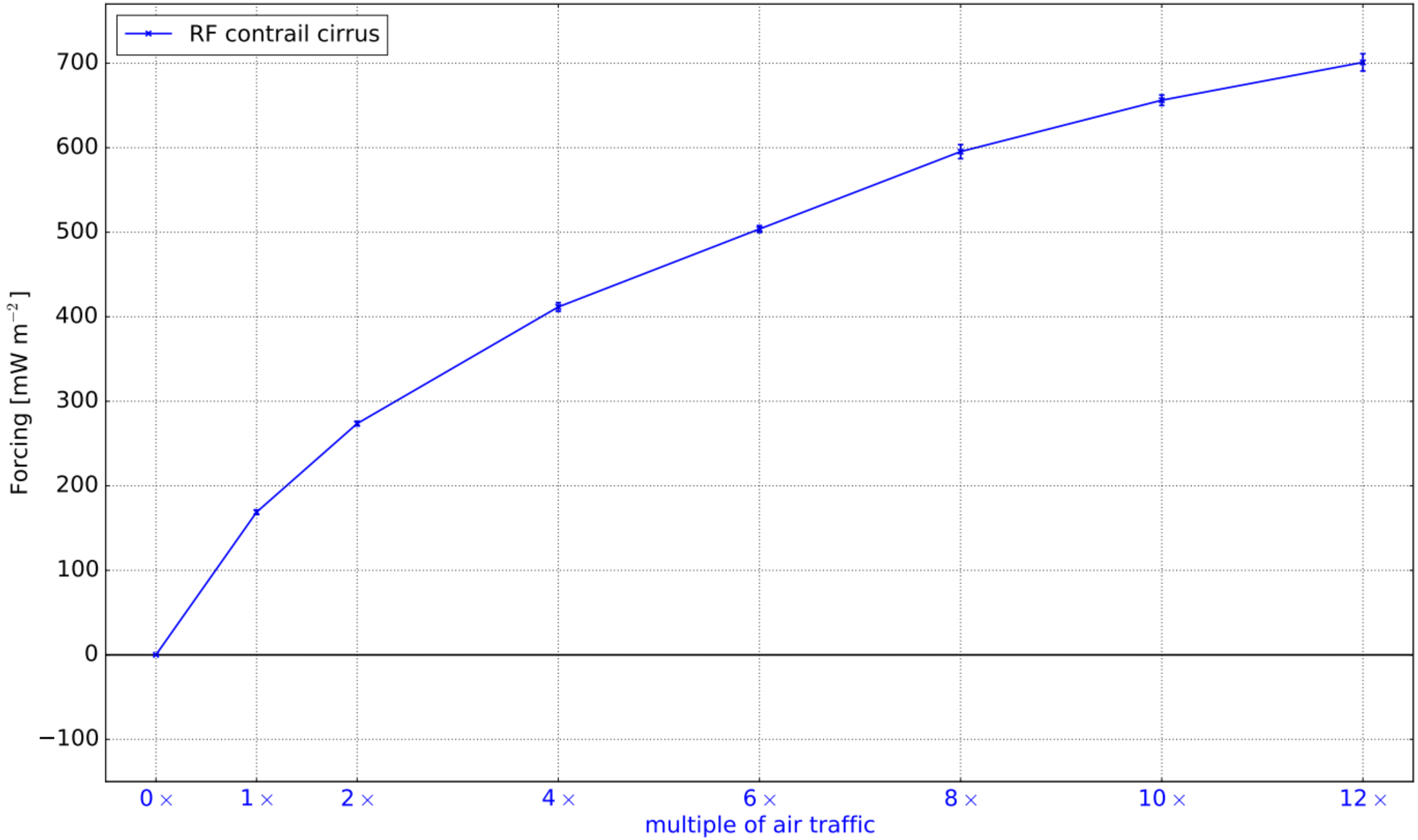
RF simulations with scaled air traffic



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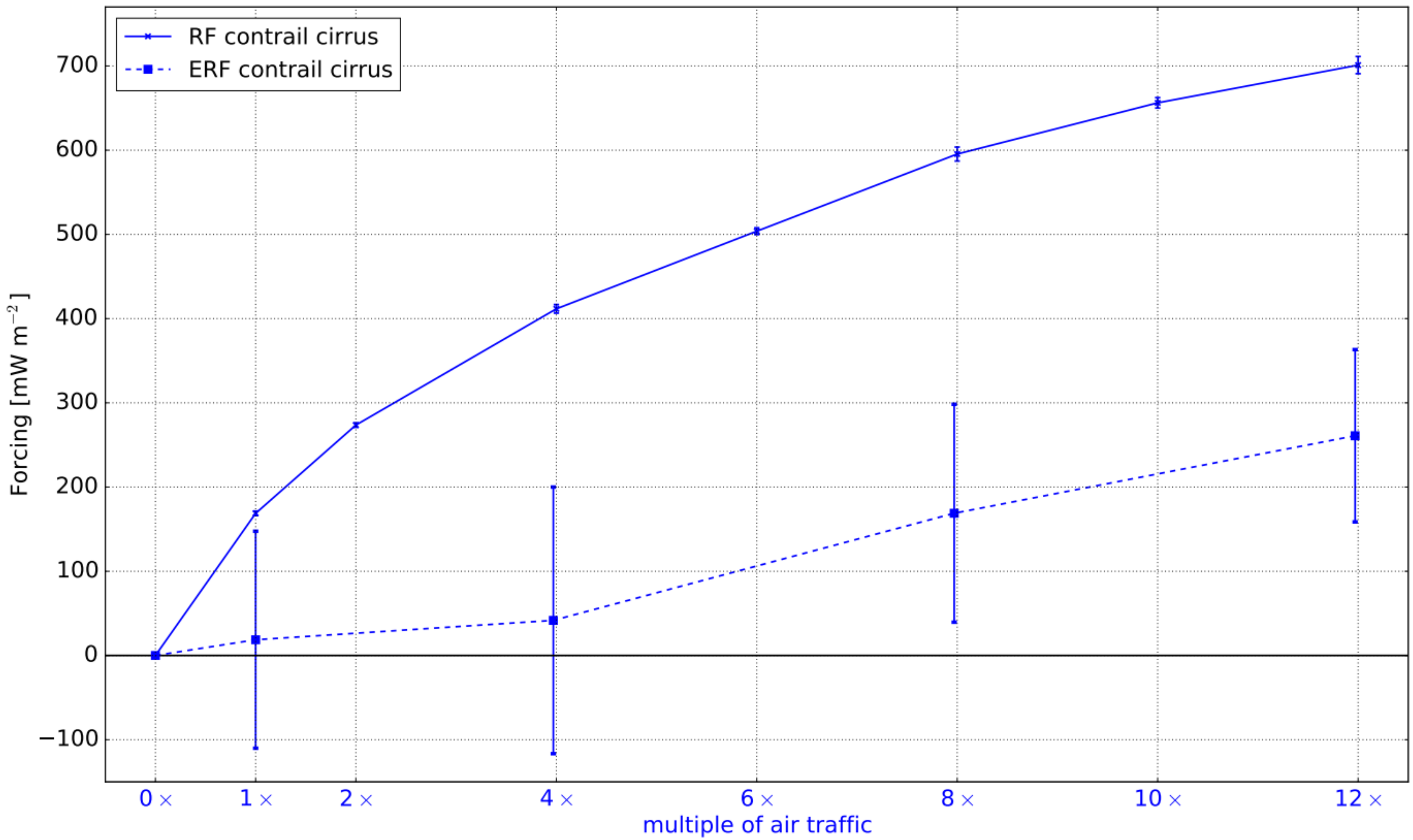

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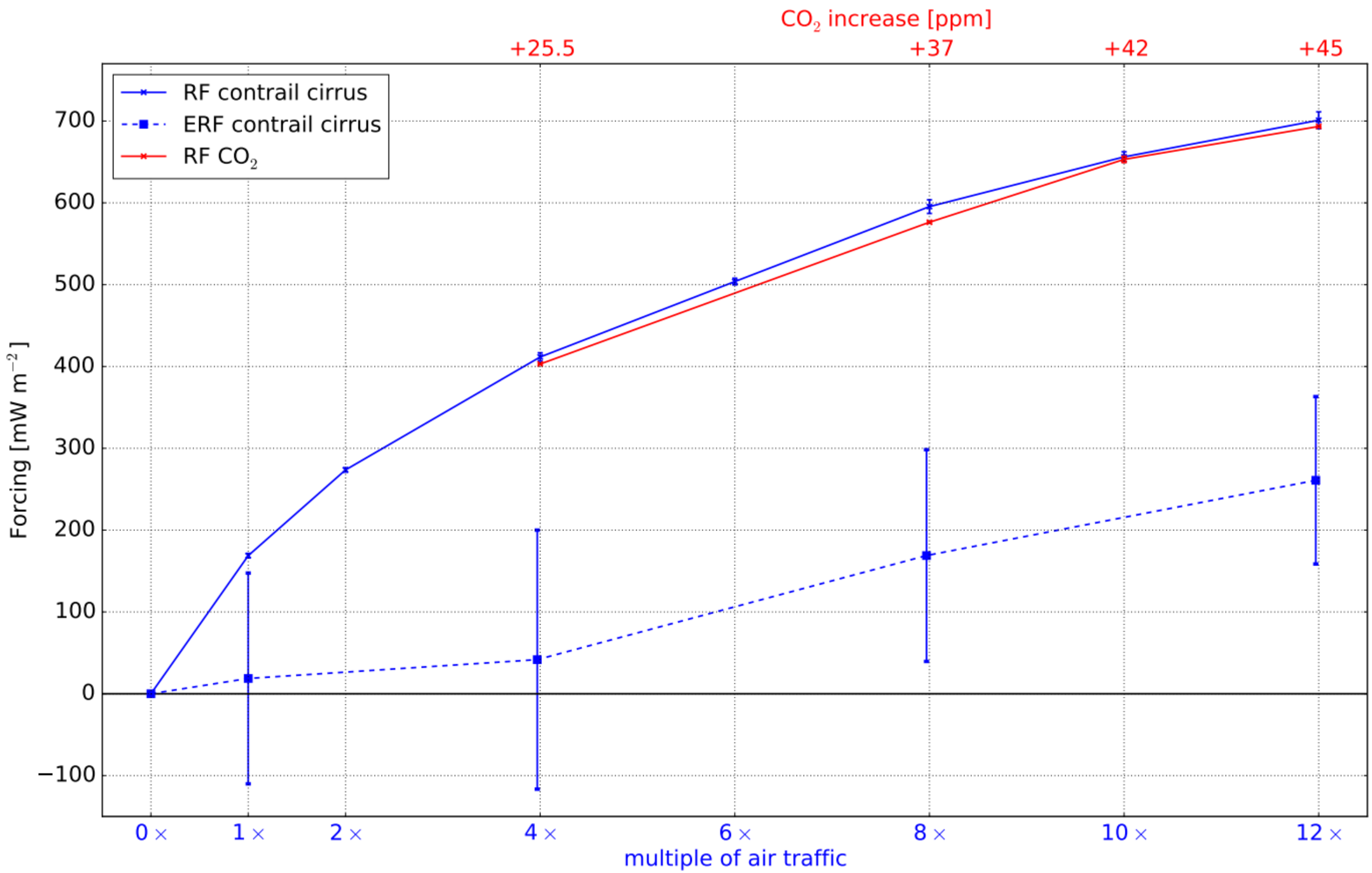

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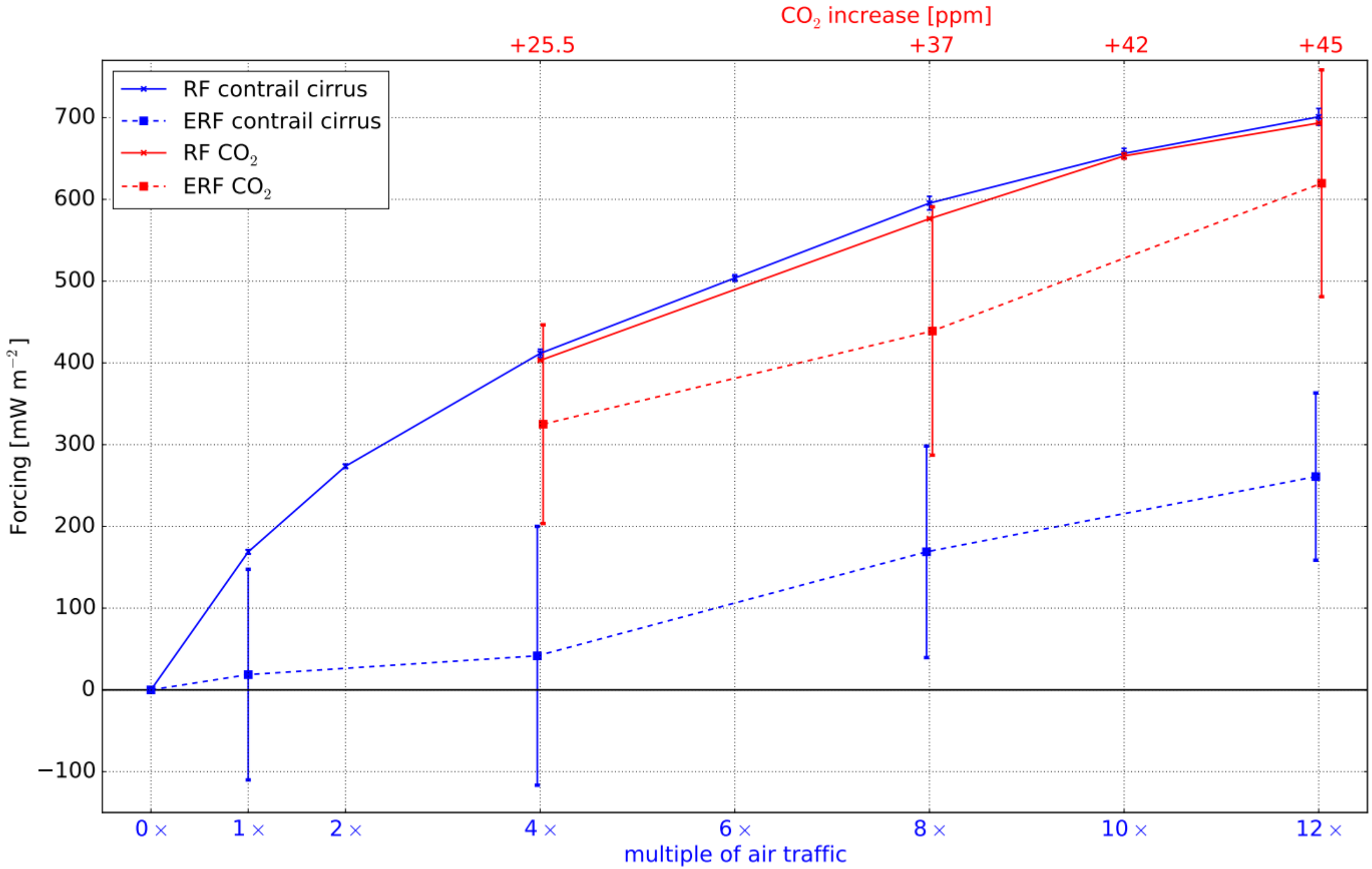

RF simulations with scaled air traffic

- Saturation in regions with high air traffic density
- Scaling of air traffic is needed to yield statistical significant results
- ERF of contrail cirrus is substantially reduced compared to its conventional RF
- The reduction of ERF is much weaker for a CO_2 forcing

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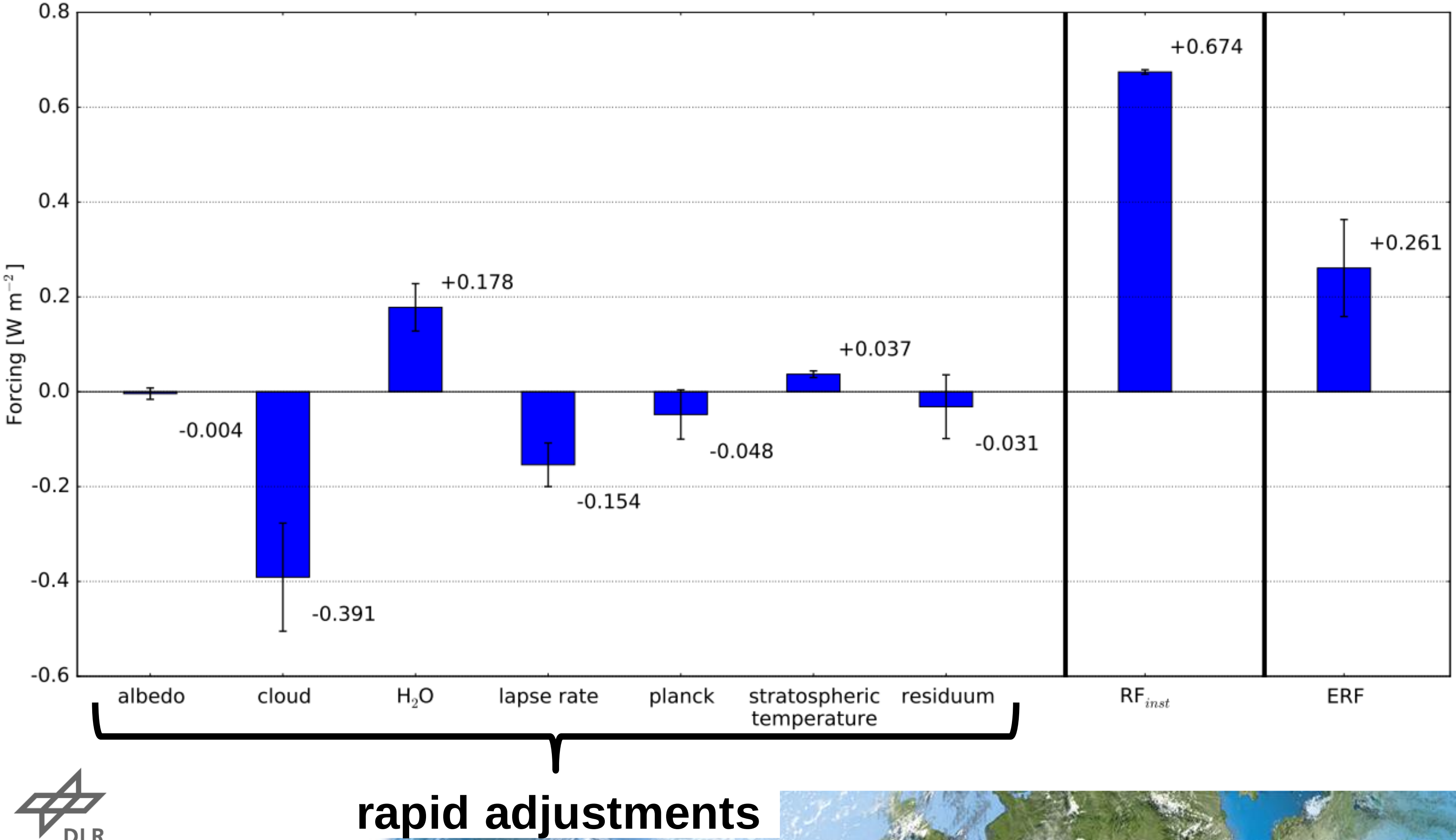
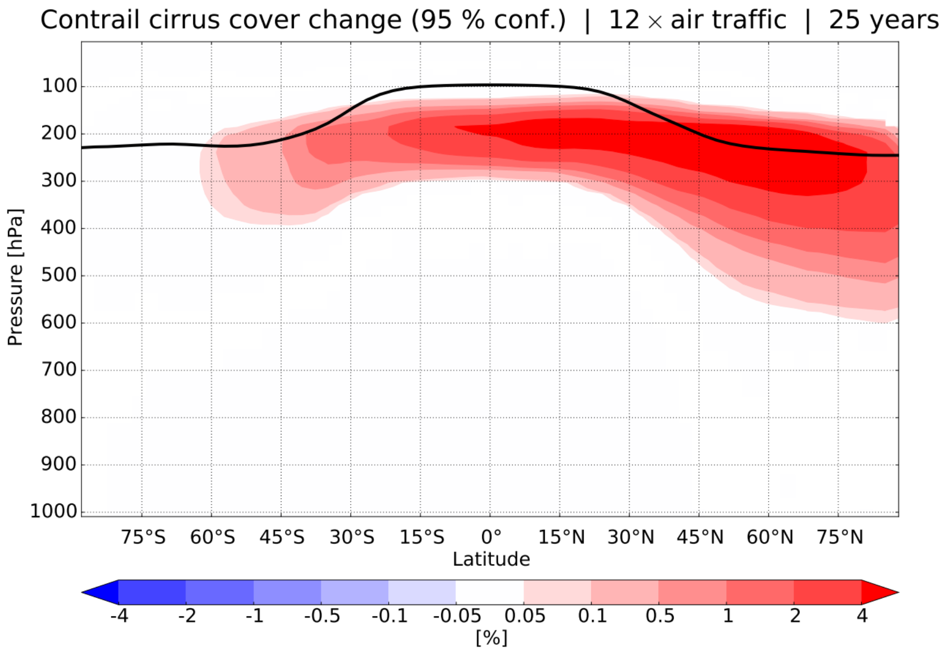
→ **Why is the ERF of contrail cirrus reduced???**

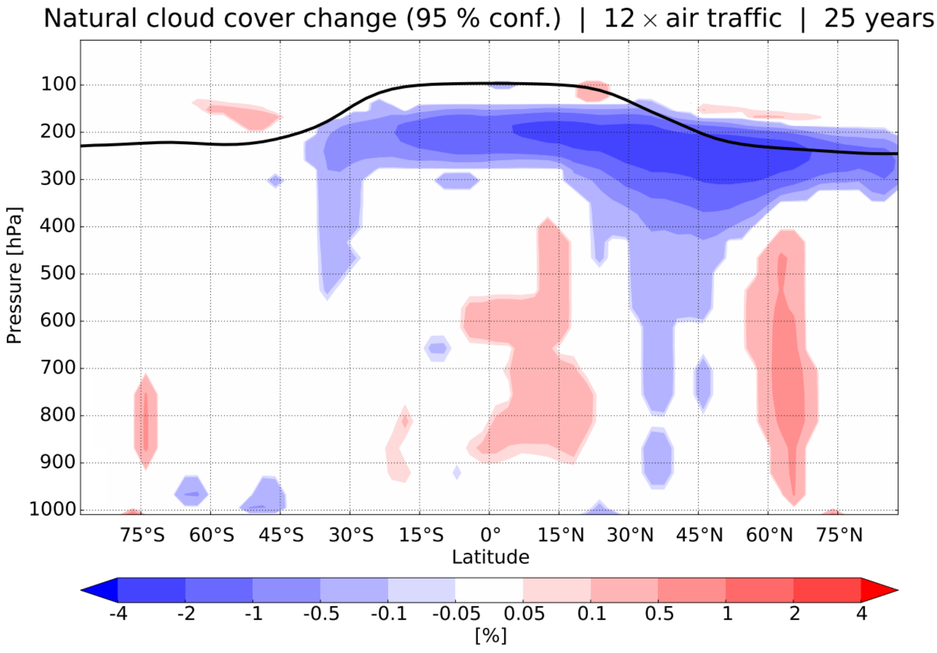
Feedback analysis: Contrail cirrus rapid adjustments



Feedback analysis: Contrail cirrus rapid adjustments

Change at 200 hPa: **+3.6 %** **-1.3 %**





→ Contrail cirrus growth at the expense of natural cirrus cover

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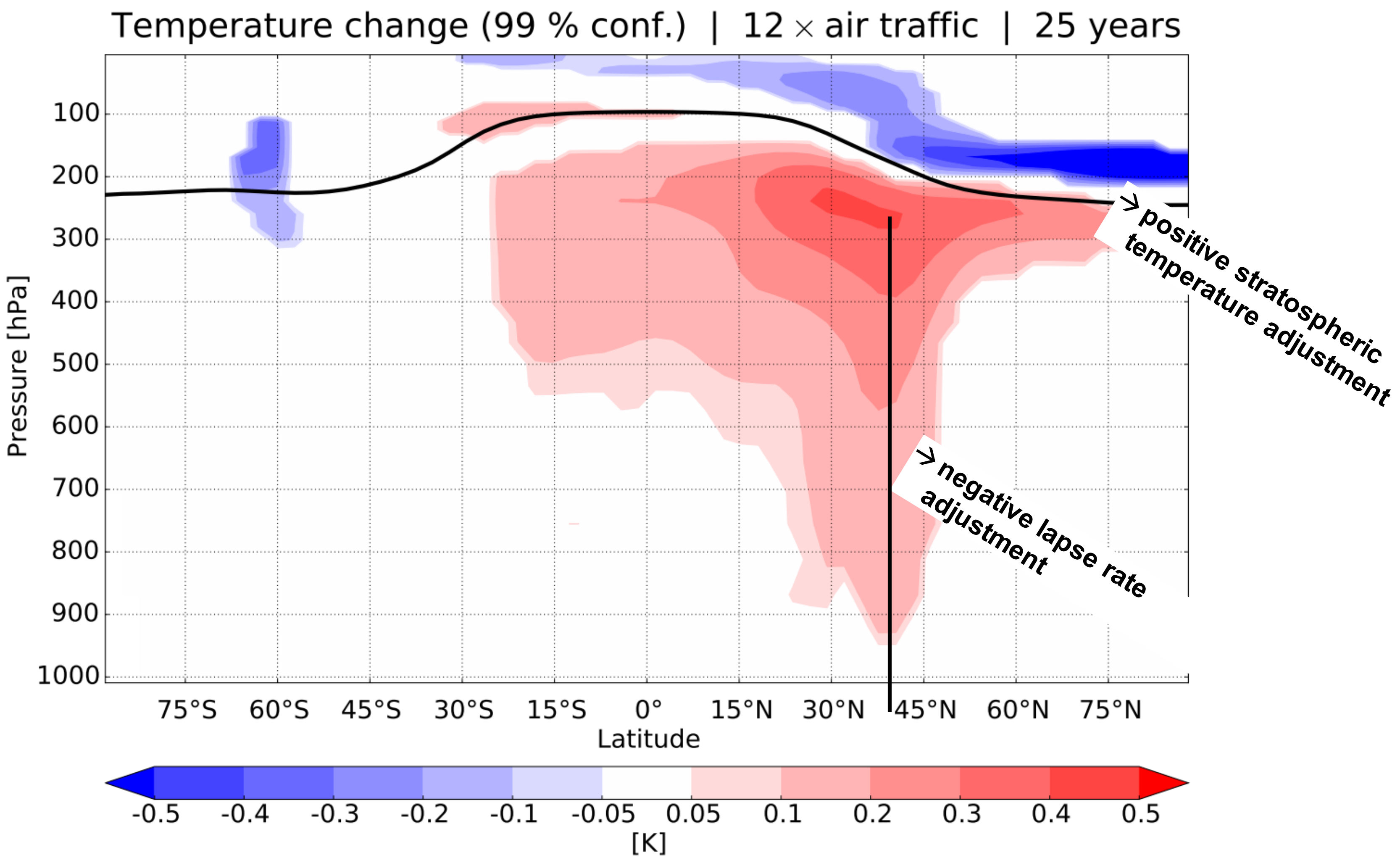
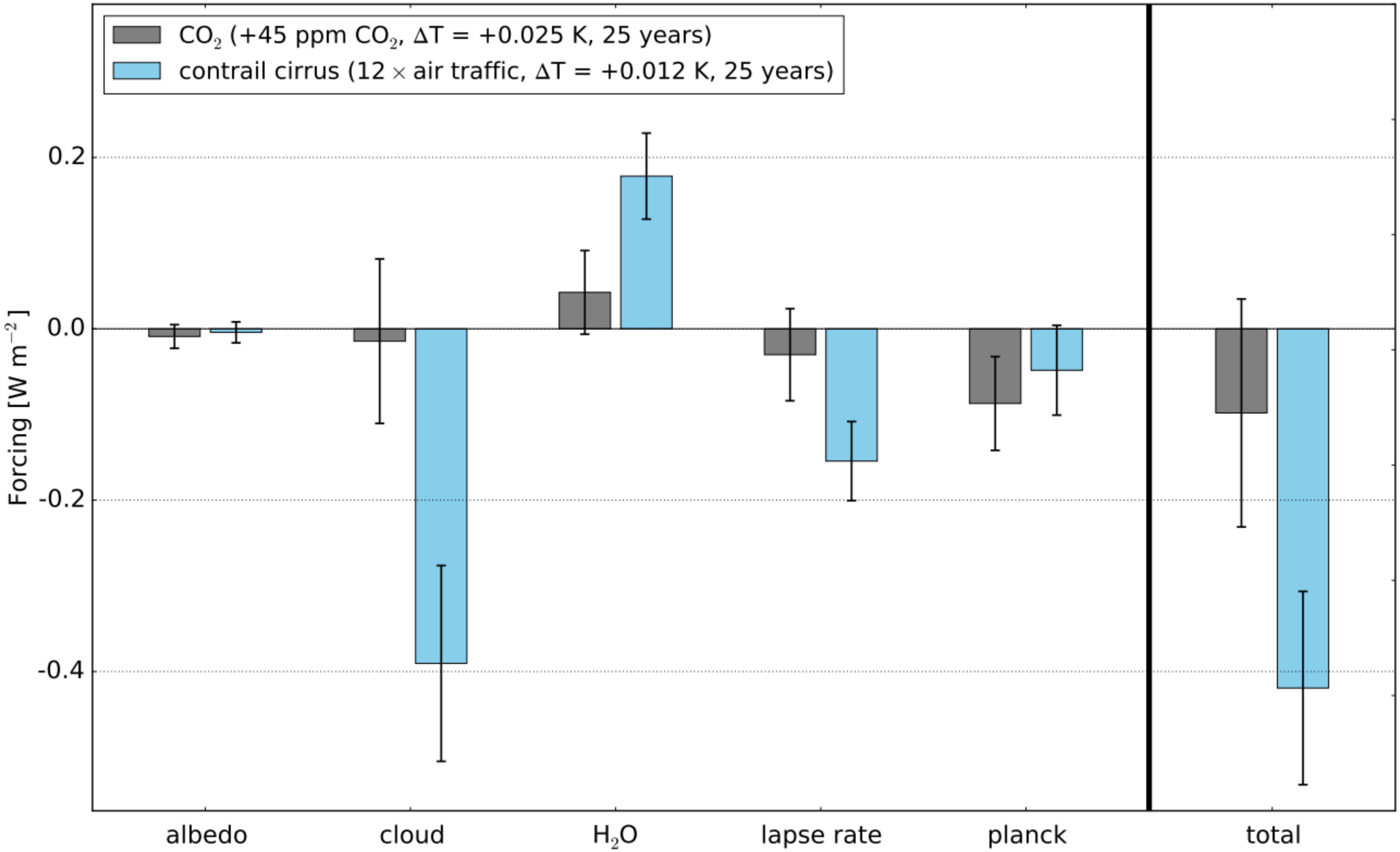


Feedback analysis: Comparison with CO_2 experiment



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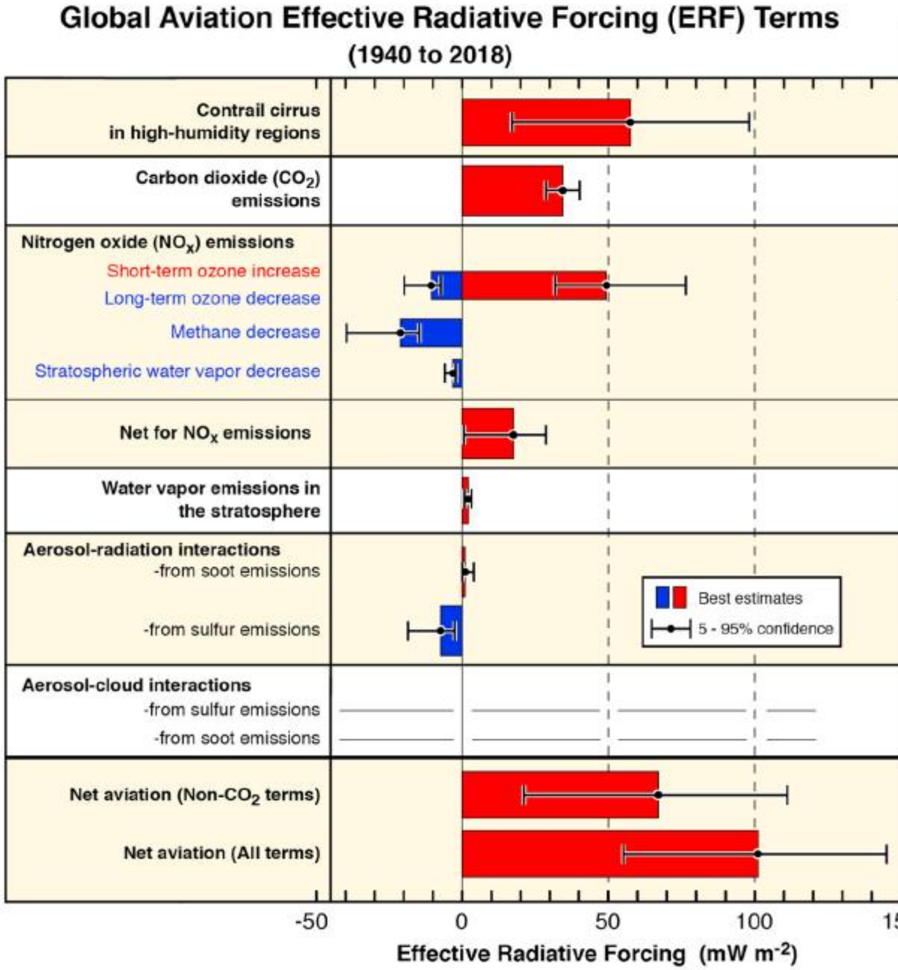
Climate impact of aviation



Term	ERF (mW m⁻²)	RF (mW m⁻²)	ERF/RF	Conf. levels
Contrail cirrus in high-humidity regions	57.4 (17, 98)	111.4 (33, 189)	0.42	Low
Carbon dioxide (CO_2) emissions	34.3 (28, 40)	34.3 (31, 38)	1.0	High
Nitrogen oxide (NO_x) emissions				
Short-term ozone increase	49.3 (32, 76)	36.0 (23, 56)	1.37	Med.
Long-term ozone decrease	-10.6 (-20, -7.4)	-9.0 (-17, -6.3)	1.18	Low
Methane decrease	-21.2 (-40, -15)	-17.9 (-34, -13)	1.18	Med.
Stratospheric water vapor decrease	-3.2 (-6.0, -2.2)	-2.7 (-5.0, -1.9)	1.18	Low
Net for NO_x emissions	17.5 (0.6, 29)	8.2 (-4.8, 16)	----	Low
Water vapor emissions in the stratosphere	2.0 (0.8, 3.2)	2.0 (0.8, 3.2)	[1]	Med.
Aerosol-radiation interactions				
-from soot emissions	0.94 (0.1, 4.0)	0.94 (0.1, 4.0)	[1]	Low
-from sulfur emissions	-7.4 (-19, -2.6)	-7.4 (-19, -2.6)	[1]	Low
Aerosol-cloud interactions				
-from sulfur emissions	No best estimates	No best estimates	----	Very low
-from soot emissions			----	
Net aviation (Non-CO_2 terms)	66.6 (21, 111)	114.8 (35, 194)	----	——
Net aviation (All terms)	100.9 (55, 145)	149.1 (70, 229)	----	——

Lee et al., 2020

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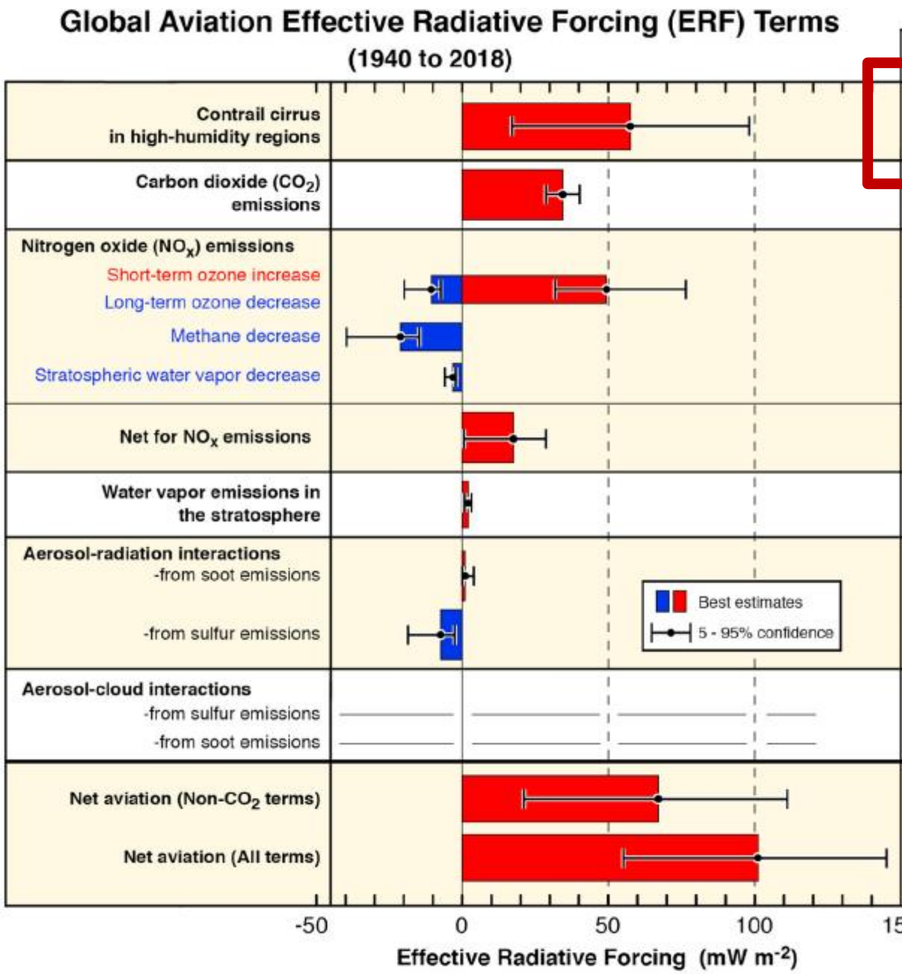

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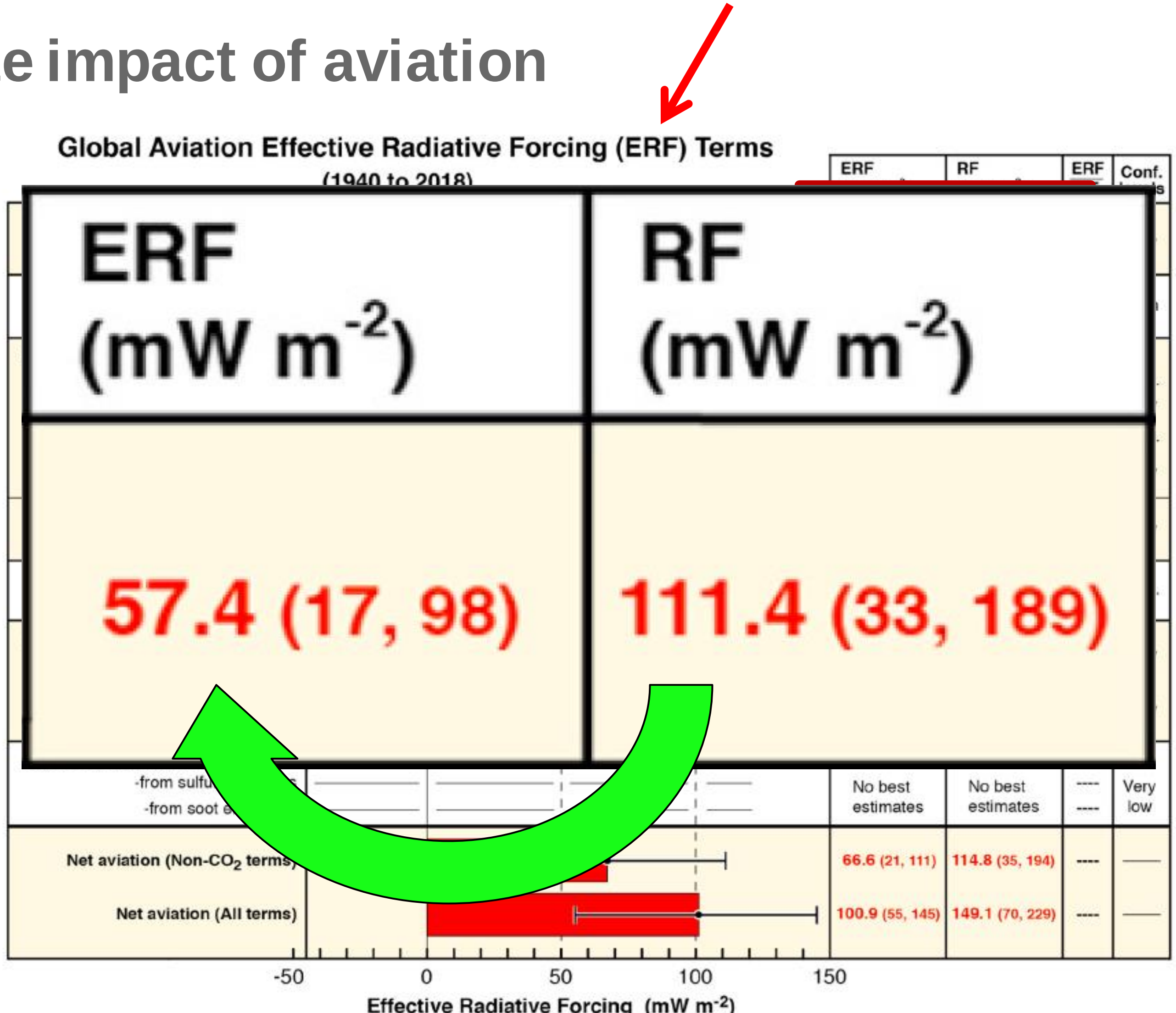
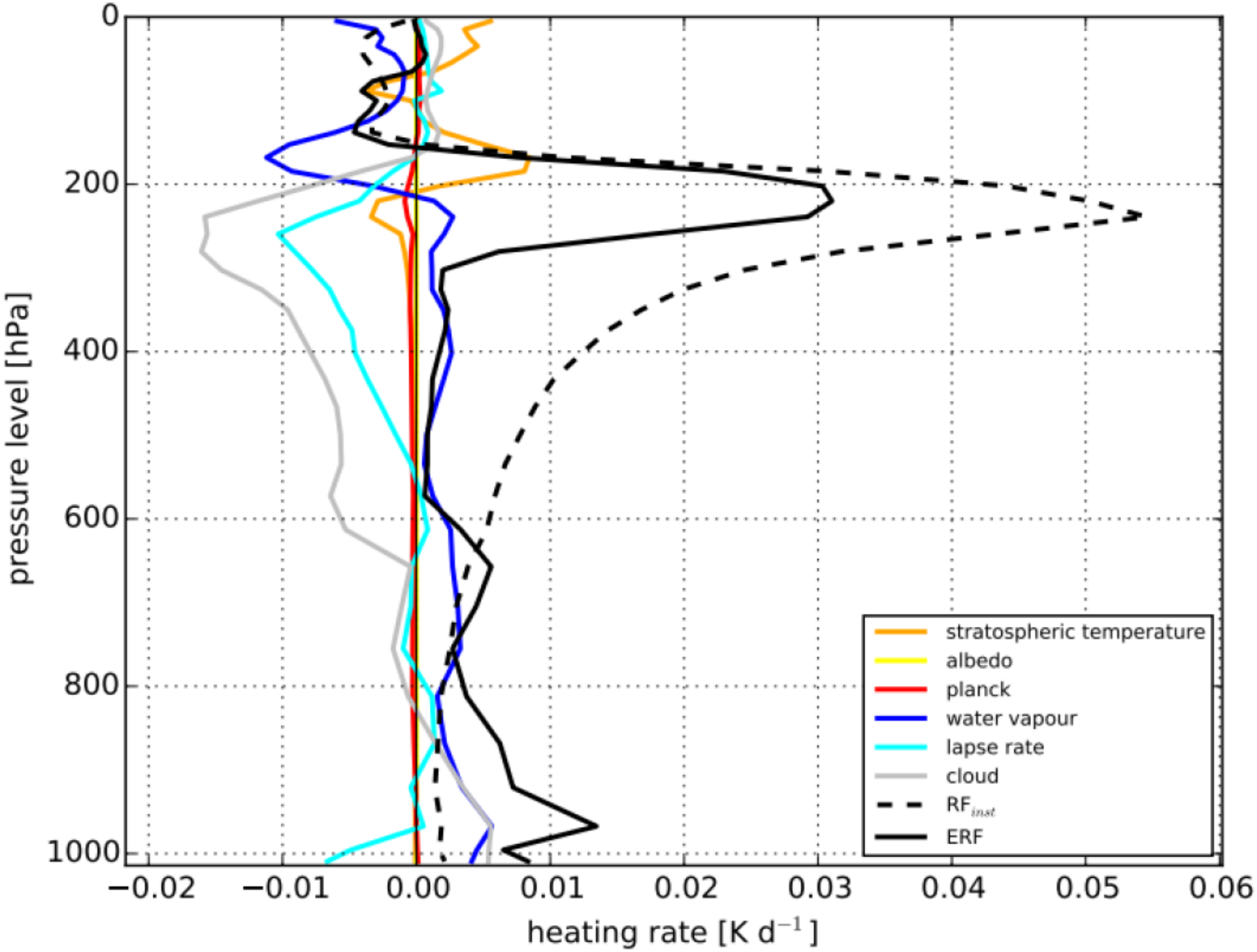


Lee et al., 2020

Heating rate profile of contrail cirrus



Climate impact of aviation

However, not the end…

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After the ERF framework r is supposed to be 1

But: Literature shows that r is not 1 for certain forcing agents (Shine et al. 2012; Marvel et al., 2016)

→ Direct simulations of the surface temperature response are needed to directly determine r and thus confirm the validity of the ERF framework for contrail cirrus

Conclusions

- **ERF of contrail cirrus is substantially reduced compared to its conventional RF**
- **Feedback analysis shows that a negative natural cloud adjustment due to a loss of natural cirrus cover is the main reason for this reduction**
- **The reduction of ERF is much weaker for a CO_2 forcing**
- **These results suggest a reduced climate impact of contrail cirrus compared to what conventional RF estimates suggest**
- **But: Direct simulations of surface temperature change are needed to confirm the actual impact of the reduced ERF for contrail cirrus**